Uncertainty Analysis Methods for Equilibrium Fuel Cycles

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Good estimates for inventories of Plutonium and minor actinides associated with advanced fuel cycles are essential for determination of requirements for repository space and for selection of fuel cycles. Likewise it is important to determine the quality of these estimates. The overall procedure for assessing uncertainties in system models with many unknown parameters involves the following general process:

1) identification of all parameters that may contribute to the uncertainties in results,
2) performance of sensitivity analyses on these parameters,
3) performance of scoping studies on all parameters that are identified to contribute to uncertainties, as determined by the sensitivity analyses,
4) conduct expert elicitations on parameters for which uncertainty distributions are not well defined,
5) assign uncertainty distributions to all parameters to be included in the uncertainty analyses,
6) conduct uncertainty analyses for all scenarios of interest,
7) refine estimates of uncertainties that contribute most to uncertainties in results, and
8) repeat steps 4 through 7 as required.

Sensitivity analyses and screening calculations are performed to determine if the parameter under consideration contributes to the uncertainty of variables included in the assessment. Where necessary, the uncertainty associated with variables selected for the assessment is determined by structured expert judgment.[1,2,3]

The Analytica 3.1[5] modeling software code is used to solve the material balance equations and to calculate distributions of results. It has a number of features that make it a good choice for this application. Some of these include the following:

1) it uses influence diagrams as an intuitive, graphical means to define and display the qualitative structure of a model.
2) it offers a hierarchical outline, an influence diagram for each module, a view of each variable with meaningful name, description, and definition, as well as charts and multidimensional tables.
3) It uses “Intelligent Arrays” to provide great flexibility in managing multiple dimensions (e.g., isotope).
4) The user can easily add or subtract dimensions without the major surgery required by a spreadsheet.
5) Changes to the dimensions of input arrays propagate through the model automatically without requiring any manual changes to downstream formulas.
6) Each multidimensional table needs a single definition (formula), rather than one for each cell.

Analytica estimates desired endpoints using probability distributions to represent uncertainties, and efficient Monte Carlo and Latin hypercube simulation to compute their implications. It also offers importance analysis to identify which uncertainties have the most impact on the results. The overall view of the model solved by Analytica is shown in Figure 1. The depleted button

permits one to choose between depleted or recycled uranium makeup feed to the fuel fabrication plant. The result and calc buttons permit one to restart calculations and to display results.

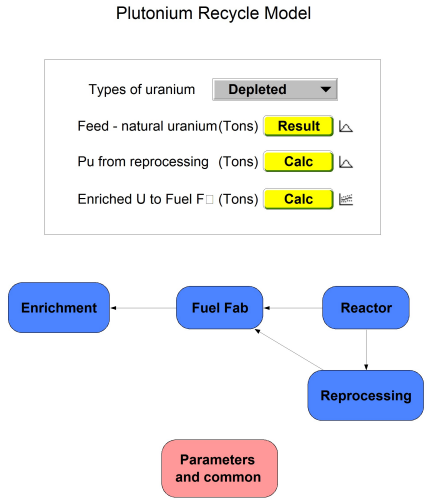

Figure 1. Overview block diagram of the Plutonium recycle model.

Table 1 lists some of the parameters used in the model with specifications of uncertainty distributions and Figure 2 illustrates an example of results.

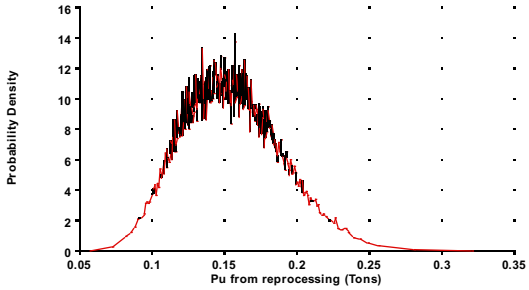

Figure 2. Probability density function of tons Pu per year per reactor.

Table 1. Specifications for parameters in the Pu recycle model

Prameter	Distribution	Specifications
Fraction of U-235 in feed to enrichment plant	Fixed	7 m
Fraction of U-235 in tails from the enrichment plant	Uniform	2 m,3 m
Fraction of U-235 in product from the enrichment plant	Triangular	0.03,0.045,0.05
Fraction of Pu-249 in spent fuel	Triangular	4 m,7 m,0.01
Relative capture to fission Pu-239 to U-235	Triangular	0.7,0.8,0.9
Fraction of U-235 in depleted U in makup feed	Uniform	2 m,3 m
Fraction of U-235 in U in from reprocessing	Uniform	0.01,0.02

The unit m denotes milli

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